

Bio-fuels

A briefing note

"The fuel of the future is going to come from fruit like apples, weeds, sawdust – almost anything. There is fuel in every bit of vegetable matter..."

Henry Ford, 1925

Executive summary

A wide variety of different agricultural crops can be turned into fuel for motor vehicles. In different parts of the world, products as diverse as sugar cane, wheat and rapeseed are used to make substitutes for petrol or diesel. These fuels are usually mixed with conventional fuels to make a blend, but some vehicles can now use pure, or almost pure, vegetable oils and alcohols.

Governments are pushing bio-fuels for two main reasons. First, they see these fuels as helpful in increasing the security of energy supplies. Second, governments believe that bio-fuels help reduce greenhouse gas emissions. For these two reasons President Bush promised significant new funds for new ethanol technologies in his recent (January 2007) State of the Union address. Privately, governments will also admit that bio fuels are good for soaking up unwanted agricultural surpluses.

There are important questions over crop-based motor fuels

- In high latitudes, bio-fuels are generally expensive to produce. In sunnier countries, this is much less true. Northern biofuels generally need subsidy to compete against petrol and diesel.
- The degree to which they genuinely avoid greenhouse gases is the subject of vigorous debate. Some opponents claim that biofuels produced in temperate regions of the world actually result in more greenhouse gas emissions than the fossil alternative. Even the optimists for bio-fuels say that current technologies are only about 30% better than petrol.
- In order to produce a significant fraction of the world's fuel, fuel crops would need to be allocated most of the land now in arable production. Even now, bio-fuels are competing with nutritional uses and pushing up food prices.
- Nevertheless, there are real grounds for optimism. Current bio-fuels technologies usually use the 'food' of the crop (oils and easily digestible starches). Huge sums are being poured into technologies that may economically use almost all plant and animal wastes. If these technologies ever work well, a large part of the world's energy problem will disappear. Another innovation uses the CO₂ from power stations to assist in growing prodigious quantities of algae that are turned into fuels.

- The public policy issues are fascinating. Today's bio-fuels do not significantly improve energy security or hold back global warming. But they may help us build a dual-fuel infrastructure, including retail petrol pumps and cars that can run on fossil and plant hydrocarbons. Do we continue to subsidise the marginal technologies available today, or push forward to cracking the problems of turning waste into ethanol?

Despite the reservations, the use of bio-fuels is likely to grow substantially as a result of government encouragement and increasing concerns over climate change. The UK, for example, has directed suppliers to put 5% bio-fuels in the overall mix of motor fuel by 2010. Though this target is most unlikely to be met, it is causing a strong pick-up in production activities and capital investment.

The global opportunity – can biomass be used to fuel a large part of the world's vehicles?

(TW = Terawatt or one billion Kilowatts)

The world captures enough energy through photosynthesis in plants and trees to completely fill all our energy needs

* Rate of energy storage in biomass	95 TW
* Consumption of energy through human activity	12 TW

At the moment only about 15% of our energy needs come from biomass

* Consumption of energy through human activity	12 TW
* Energy consumption in the form of biomass	1.7TW

We could comfortably capture at least half our energy needs by exploiting plants

Consumption of energy through human activity	12 TW
Biomass resources available for conversion to fuel 2030	6 TW

Food needs do not take a substantial fraction of total biomass creation

* Rate of energy storage in biomass	95 TW
* Human consumption of energy in the form of food	0.3TW

(Source: Amended from lecture notes of Professor Nick Jelley of Oxford University)

The biofuels challenge is a simple one to state. We need to get as much as possible of our global 12TW energy needs from plant matter, without disrupting the 0.3TW we need to use as food. If economic and population growth continue, these numbers will increase at 2-4% each year.

Fuels in the UK – the key numbers.

Total demand for motor fuels in the UK is about 38 million tonnes a year. About three quarters of the total is sold at retail, with the rest supplied directly to commercial customers. Petrol and diesel have about half of the market each. Latest figures suggest that motor vehicles (cars, vans, buses and lorries) are responsible for about 125m tonnes of carbon dioxide in the UK each year, or just over 20% of total CO2 emissions.

Improvements in energy efficiency have slightly reduced fuel consumption per mile driven. Nevertheless, demand for motor fuels is growing at about 1% a year as a result of increasing numbers of cars and worsening congestion. Freight transport mileage is growing, however the average car is travelling a slightly shorter distance each year. The most recent data also suggests that UK new car buyers are shifting away from larger vehicles such as SUVs, and typical fuel economy is tending to improve as a consequence.

The large role that motor fuels play in the UK greenhouse gas inventory makes it an important target for reduction. Bio-fuels are seen as an important weapon. Currently, however, they form less than 1% of the mix of fuels. In the US, the figure is about 3% of petrol supplied to cars.

Proportions

Modern diesel cars can run well on mixtures up to at least 10% bio-diesel. In fact, bio-diesel may improve engine performance and reduce wear. Nevertheless, 5% biodiesel is the blend generally sold in the UK. This can be sold at conventional pumps without any labelling because the product is within the tolerances allowed for conventional diesel. However, bio-diesel is not chemically identical to fossil diesel and provides about 10% less power per unit volume. Those retail customers now buying a bio-diesel blend may not be aware of the very small penalty in fuel economy.

With small adjustments, cars and freight vehicles can run on blends up to 100% bio-diesel. In the UK and elsewhere, vehicles running on 100% bio fuel are generally using waste vegetable oil from catering institutions. The observant will recognise these cars by the slight odour of the fish and chop as they pass. Tesco is now running its lorry fleet on 50% bio-diesel, sold by its affiliate company Greenergy and made from rapeseed in a refinery in the north east of England. Tesco's vehicles can refuel at its own depots so it does not have to worry about the shortage of locations at which this blend is sold.

Conventional petrol cars need new equipment if their owners want to use more than about 10% of ethanol by volume. Increasingly, car manufacturers are making 'flexible fuel' cars that can accept varying proportions of ethanol in the petrol. 85% ethanol ('E85') is increasingly the blend of choice in countries as different as Sweden and the US but relatively few filling stations sell the product. Models sold as 'E85' will run on 85% ethanol, but automatically switch to the settings for conventional petrol when the car's tank is filled at an ordinary filling station. Among other changes, the injection system

puts a little more fuel into the cylinders every cycle, to compensate for the lower power available from each sip of ethanol. Even in the US, there are still very few outlets selling E85, so cars need to be adaptable. Brazil will be the first country to get a complete network of ethanol pumps for retail sale of fuel.

Manufacturing techniques

Biodiesel is usually made by processing rapeseed oil or soya bean oil. Relatively limited chemical changes make the food oils useful in a conventional diesel engine. (Indeed most diesel engines can run on used vegetable oils straight from a domestic deep fat fryer provided some minor fuel line components are changed). In the US, most biodiesel is made from soya, but in the UK rapeseed provides the feedstock

By contrast, bio-ethanol is a replacement for conventional petrol. It is usually made from sugar cane, wheat or corn (maize). In the case of corn, the predominant feedstock in the US, the kernels are ground up, starches are turned to sugars, and these are then fermented turn into ethanol. The world's most advanced bio-ethanol market – Brazil – uses sugar cane.

Thus biodiesel can be thought of as a modified vegetable oil and bio-ethanol an alcohol made from sugars. In both cases, the manufacturing process is using an animal or human foodstuff as the ingredient for a fuel. This is important for two reasons: first, food is valuable and, second, the land to productively grow food is in short supply.

Biodiesel has about 90% the energy value of fossil diesel but ethanol is slightly less than 70% as calorific. While modern diesel cars can run on quite high concentrations of bio fuel, the typical car on the road will only run on percentages of ethanol lower than about 10%.

The big issues

Production costs

As background, at the end of January 2007, crude oil for use in refineries costs about 35p a litre. Refining might add another 5p on to this cost, making a total of 40p.

In the UK bio-diesel is subsidised by a duty reduction of 20p per litre. Therefore if biodiesel costs about 60p a litre to make, it would be approximately the same value to the fuel companies as fuel derived from crude oil.

In the UK, the main supplier of bio-diesel, Greenergy, appears to make money on its processing of sales of rapeseed into bio-diesel, at least if its latest accounts are any guide. The company has also attracted new investors in the last year, suggesting that its business model is reasonably robust. But at a cost 60p a litre, bio-diesel needs a subsidy from fuel duty reduction until the price of crude rises to over \$80 a barrel. Improvements in the scale of the production plants and other cost reductions may improve the underlying

competitiveness of the fuel. Certainly, the data from the US suggests that ethanol now costs less to make than it did ten years ago.

In Sweden, ethanol production appears to be slightly cheaper than UK diesel but the fuel is generally made from grain, which has increased recently substantially in price.

US figures for the cost of corn ethanol appear to suggest that the cost about 15p per litre, or 20p if the lower energy value is taken into account. This figure is pushed down by the subsidy for maize production, and the true cost may well be more than 50% higher than this. This suggests, very broadly speaking, that underlying corn ethanol costs are about the same as fossil petroleum at today's oil price.

Because of a poor data sources, these numbers are little more than speculation. The key point, we think, is that the economics of all bio-fuels in temperate countries are currently dependent on decisions about government subsidy, whether the money flows through agricultural support, or through reductions in fuel duty. In tropical countries, today's fuel prices probably justify investment in the current generation of bio-fuels without any subsidy.

Land use

In the UK, a hectare will produce about 1,200 litres of rapeseed-based biodiesel, as well as several other low-value by-products. To meet the total motor fuel demand of the UK, about 38m hectares would need to be devoted to bio-fuel production. This is over 150% of the land area of the UK, and eight times the area currently devoted to all crops. A densely packed country in the high latitudes cannot meet more than a small fraction of all its fuel needs from the 'food' portion of crops. It is a sobering reflection on modern energy needs that the UK can get most of its food energy from 4.4m hectares, but that its cars and lorries would need eight times as much to move us around.

Most commentators think that the UK will struggle to meet more than 5-10% of its fuel needs from bio-crops. We also need to remember that crops grown to be transformed into motor fuels will tend to displace food crops. This will either result in more flows of imported food or will cause countries like the UK to bring in marginal land into production, which characteristically need higher inputs of fossil fuel based fertiliser. One of the two major UK producers of bio-diesel indicates that it already uses 10% of the country's entire output of oil seed rape.

In the US, the issues are already beginning to become visible. The price of corn is rising as production is sucked into the ethanol factories, and away from use as a human and animal food. 20% of all US maize is now converted into ethanol though this only produces about 3% of all car fuel. Very approximately, adding 1% to this figure requires another 1% of the land area of the US. Even in a very large country that is much less densely populated than the UK, the expansion of ethanol production is going to stretch the availability of decent quality farmland.

In the US, corn will currently produce about 3,700 litres of ethanol a hectare. The higher temperatures produce higher yields than in the UK, though it is important to remember that ethanol has a lower energy content per litre than bio-diesel.

Air quality

In large portions of urban areas, air quality is not at a standard that avoids increased respiratory and other diseases. Bio ethanol and diesel are both significantly better at maintaining air quality, though diesel will slightly increase emissions of nitrogen oxides. Particularly for public transport operators, there is strong reason to use biofuels in the centre of cities. UK operators such as Stagecoach have committed to purchasing a 5% biodiesel blend. In theory this ought to have slightly reduced the efficiency of Stagecoach's vehicles, but it reports no impact on fuel consumption.

Global warming implications

The diagrams produced by the proponents of bio products all show a neat cycle of carbon. Energy from the sun is captured by the growing plant through the photosynthesis process. The vegetable is processed and turned into fuel. In the form of vegetable oil or plant alcohol (ethanol) the fuel is then burnt in an engine which returns the sequestered carbon to the atmosphere. The drawings are nice but the reality is far from as simple.

Greenhouse gases are created during the production and processing of fuel crops at every stage of the production cycle.

- Crops grown in temperate lands, such as the UK, need high inputs of nitrogenous fertiliser. This fertiliser is made using a process that employing natural gas. A tonne of fertiliser might need 15,000 kilowatt hours of energy to make. (1% of the world's energy is used to make nitrogen fertilisers).
- The application of nitrogen fertiliser to the soil produces a small amount of nitrous oxide as a result of chemical reactions. Nitrous oxide is a very powerful global warming gas, of approximately 300 times the effect of carbon dioxide, so even the small quantities produced have an important effect. Agriculture is the most important land-based source of nitrous oxide.
- Farming processes such as tilling, ploughing, harvesting and drying use fossil fuels.
- Transport of the crops needs diesel fuel
- The manufacturing processes need substantial amounts of external energy to produce the finished fuel.

The arguments rage on whether bio fuels grown in higher latitudes add or reduce the greenhouse gas emissions. Most observers believe that bio crops save some CO₂. A saving of 30% CO₂ might be a typical estimate.

However these estimates generally exclude the effect of nitrous oxide emissions from fertiliser use. The Intergovernmental Panel on Climate Change originally suggested that emissions of nitrous oxide might average about 1% of the original weight of the fertiliser but this body put extremely wide limits around this estimate. Nitrous oxide emissions have only recently been measured with greater accuracy.. More recently, work in the UK and elsewhere suggests that the real figure might be as high as 2%. Given that nitrous oxide is 300 times as powerful as carbon dioxide, this makes a huge difference to the estimates of the net global warming effect of bio-fuels.

Furthermore, these calculations do not make the more demanding comparison as to whether the land used for bio-fuels would not be better employed to sequester carbon in the form of permanent tree cover. As with so many other things, the science of this is not yet settled, but it may well be better for the global atmosphere for marginal land to be given over to tree-planting rather than fuel production.

In tropical countries, such as Brazil, crops such as sugar cane can be grown with a much higher yield than rapeseed in the UK. Recent figures suggest that Brazil can make 6,000 litres of ethanol from a hectare of sugar cane, five times the output of a UK rape field. Cane also requires less processing because it is largely sugar in the field and does not need to be converted from starch. As we shown in the section on product economics, this means ethanol can be competitive per mile driven with petrol, but only in countries with sufficient sun to create good yields of sugars in their crops. By contrast biodiesel in the UK or ethanol in Sweden will require substantial subsidy unless oil prices or petrol duties increase very substantially.

Technology changes

Bio-butanol

BP and other fuel producers are interested in moving away from ethanol and towards butanol. A joint UK venture between BP and DuPont will produce the butanol from a modified ethanol plant. BP says that butanol because it has an energy value similar to petrol, can be put into pipelines and integrated easily into existing distribution systems and has fewer potential problems with water contamination. All in all, this means that present cars can be comfortably run on a mixture of up to 16% butanol by volume. The companies see wheat as the best feedstock from the UK but this invites the question as to whether the current generation of biofuels will adversely affect the consumer price of foodstuffs. Rapeseed is a crop largely grown because of EU subsidies in the UK, rather than because of market need. But wheat is an important ingredient of supermarket foodstuffs and has increased substantially in price recently as a result of Australian drought and changing tastes in Asia.

Cellulosic ethanol

In the US and elsewhere, the race is on to use discarded wastes from agriculture and forestry to make ethanol at competitive prices. This makes obvious sense. If a company can use sawdust, straw, animal manure, waste from food processing or even discarded paper as a feedstock, the raw materials costs will be low, the need for additional land and extra fertiliser non-existent and the product will not inflate the price of food. And even if waste doesn't work, low value crops such as tropical grasses can produce very much ethanol from a hectare of land than we can get from maize cobs.

The obstacles lie in the chemistry of the proposed raw materials. The structures of plant matter are largely built in cellulose, a tough material that is extremely difficult to break down. Sugars can be fermented easily (and have been used to make alcoholic drink since the dawn of human existence) but cellulose resists fermentation. It needs to be chemically split by heat, acids or enzymes before it releases sugars that can be fermented into ethanol.

If it proves possible to convert large volumes of cellulosic material into ethanol, the yields per acre may be six times as great as the volumes from food starches, at least if US estimates prove accurate. Instead of creating a 30% saving in carbon output, the high yields and very low requirements for fertiliser may produce an 80% advantage from cellulosic conversion. This is not just standard investor optimism. Even normally cautious US government laboratories are interested in the carbon saving benefits of ethanol from waste.

The Argonne National Laboratory puts it as follows when talking about the pilot plants.

Conventional ethanol produced 20 to 30 percent fewer emissions than gasoline, while cellulose ethanol produced 80 percent fewer emissions – a much more noticeable improvement. Also, since this form of ethanol is produced mostly from waste, it is far more economical to produce.

Finding cost effective (and energy efficient) ways of breaking down cellulose is one of the most interesting technical challenges in the world today. The billionaire US venture capital investor Vinod Khosla has placed a number of large bets on different approaches to the problem and the companies working on these varying techniques.

- Celunol, using microbes to assist in the fermentation process
- Kergy, heating biomass in the absence of air to produce hydrogen and carbon monoxide, which are then recombined into ethanol
- E3 Fuels, at a huge integrated cattle and corn farm, cow manure produces methane to power the fermentation process. (The interest in this approach is its energy efficiency rather than its techniques for breaking down cellulose).
- Mascoma, new enzymes for breaking down agricultural wastes.

None of these companies - or the twenty or so others that are working furiously to be first to market - has demonstrated successful production of large amounts of ethanol from cellulosic materials. This is probably just a matter of time, though some scientists remain acutely sceptical. When, and if, the breakthrough comes, the consequences should include a substantial fall in the energy cost of making the fuel that power vehicles. DuPont, which has substantial interests in the field of bio-fuels, says that it expects significant output from cellulosic ethanol plants 'within the 2011 to 2013 timeframe'.

Ethanol from algae

In another example of a technology that is trying to use waste material to create bio-fuels, a couple of US companies are completing work on capturing CO₂ from power stations and then feeding the gas across beds of algae growing in tubes. Combined with natural light, carbon dioxide is a powerful fuel for organism growth and hugely speeds up the growth of the algae, which can then be turned into bio-diesel and ethanol. Yields from this process are likely to be extremely high per unit of land used to grow the algae. Cellulosic conversion may produce 25,000 litres of fuel each year from a hectare of space, but proponents talk of CO₂-boosted algae creating over 150,000 litres of ethanol and diesel. This process will avoid the overcrowding that is likely to result from conventional crops being diverted from food to energy use. The technology is exciting high levels of interest but is still only at an early stage of development.

Flexible fuel vehicles

Conventional petrol cars need new equipment if their owners want to use more than about 10% of ethanol by volume. Diesel cars are more adaptable, but still need adjustments if the vehicle is to run for a sustained period on the bio product.

Increasingly manufacturers in Brazil, the US and elsewhere are producing new vehicles that run on varying concentrations of ethanol. Models sold as 'E85' will run on 85% ethanol, but automatically switch to the settings for conventional petrol when the car's tank is filled at an ordinary filling station. Among other changes, the injection system works out the strength of the mixture and puts a little more fuel into the cylinders every cycle to compensate for the lower power available from each sip of ethanol. Even in the US, there are still very few outlets selling E85, so cars need to be adaptable.

Subsidies, lobbying and global trade politics

The bio-fuels industry sits at the centre of some of the world's most difficult political issues. Climate change, energy security and the subsidy of farm outputs are all issues that are touched by the raging bio-fuel debates. Is the headlong rush to bio-fuels forcing up the price of corn breads for the poor in countries like Mexico? Is the European scheme for mandating proportions of ethanol or bio-diesel just a backdoor way of subsidising

inefficient farmers? Does the extra fertiliser used to grow bio-fuels make a net addition to greenhouse gases? The list of debates surrounding bio-fuels is long and the questions are far from settled.

One perfect example is the impact of the EU's renewable fuel obligation regulations, which demand that 5% of all fuels sold are made from biological sources. One of the main impacts of this rule has been to raise the incentives for tropical farmers to cut down forest and replace it with palm plantations in order to harvest more palm oil, which can be used for bio-diesel in Europe. While the argument still rages as to whether it makes sense to reforest northern Europe, no-one denies that tropical woodland is extremely important to the maintenance of a stable climate. The unfortunate fact is that if we get our bio-fuels by importing from South Asia, the net impact on the global atmosphere is almost certainly detrimental.

We have referred already to the observable effect of the ethanol boom on corn prices in North America. At first sight, this looks a good outcome – farmers that struggled to survive through the 1990's are now getting a better price for their product. But the impact is being felt on the prices of food that use corn as an ingredient. Farmers are switching their production to corn in response to prices, which tends to decrease the output of alternative crops such as soya beans.

In the UK and the rest of Europe, the painful reconstruction of the Common Agricultural Policy and the gradual withdrawal of export subsidies for commodities such as sugar, means that governments have been tempted to see bio-fuels as a way of propping affected farmers. It is probably no coincidence that the first UK bio-ethanol plant has come into production using sugar beet that would otherwise have been turned into sugar and dumped abroad. What looks like climate virtue from the UK government may actually often be old-fashioned subsidy politics.

The plausible solution to the urgent need to reduce the net carbon output from vehicles - other than a reduction in the demand for motor fuels using tax increases - is the development of cellulosic or algae-based bio-fuel industries. Only if fuel doesn't take extra land, disrupt commodity markets or require special subsidy will it meet our climate change, energy security and food availability needs. The problem is that scale cellulosic ethanol production is almost certainly ten years away which time world's motor fuel needs will have gone up by another twenty per cent or more.